AD-F300 853

10

AD A129087

AD

TECHNICAL REPORT ARBRL-TR-02490

STRAND BURN RATES OF BLACK POWDER TO ONE HUNDRED ATMOSPHERES

Ronald A. Sasse'

May 1983

US ARMY ARMAMENT RESEARCH AND DEVELOPMENT COMMAND
BALLISTIC RESEARCH LABORATORY
ABERDEEN PROVING GROUND, MARYLAND

Approved for public release; distribution unlimited.

83 05 18 054

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER: TECHNICAL REPORT ARBRL-TR-02490
2. GOVT ACCESSION NO.: AD-A129 687
3. RECIPIENT'S CATALOG NUMBER:
4. TITLE (and Subtitle): STRAND BURN RATES OF BLACK POWDER TO ONE HUNDRED ATMOSPHERES
5. TYPE OF REPORT & PERIOD COVERED: Technical Report
6. PERFORMING ORG. REPORT NUMBER:
7. AUTHOR(s): RONALD A. SASSE'
8. CONTRACT OR GRANT NUMBER(s):
9. PERFORMING ORGANIZATION NAME AND ADDRESS: U.S. Army Ballistic Research Laboratory, ATTN: DRDAR-BLI, Aberdeen Proving Ground, MD 21005
10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS: 1L162618AH80
11. CONTROLLING OFFICE NAME AND ADDRESS: US Army Armament Research & Development Command, US Army Ballistic Research Laboratory (DRDAR-BLA-S), Aberdeen Proving Ground, MD 21005
12. REPORT DATE: May 1983
13. NUMBER OF PAGES: 35
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office):
15. SECURITY CLASS. (of this report): UNCLASSIFIED
15a. DECLASSIFICATION/DOWNGRADING SCHEDULE:
16. DISTRIBUTION STATEMENT (of this Report): Approved for public release; distribution unlimited
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report):
18. SUPPLEMENTARY NOTES:
19. KEY WORDS (Continue on reverse side if necessary and identify by block number):

Black powder
Propellant
Physical Properties of Black Powder
Burn Rate
Strand Burn Rate

20. ABSTRACT (Continue on reverse side if necessary and identify by block number) raj

Black powder samples were compressed into parallelepipeds of several different densities. Strand burn rates of these samples were determined by high-speed cinematography at constant pressures to 100 atmospheres. The rate can be represented as $r = 1.72\ p^{0.164}$, with the regression rate, r, in cm/sec and pressure, p, in atmospheres. High-speed movies, 2000 frames per second, showed the combustion mode, droplet-particle formation, and images that were used to derive both surface and strand burn rates.

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

20. Compaction of black powder meal was found to be a linear logarithmic function of applied pressure, where samples of different moisture content formed a family of parallel lines. This same functional relationship was found when compressing grains of black powder and copper spheres. This similarity suggests the same physical processes are occurring in both materials where compaction results in plastic flow among a collection of close packed spheres.

TABLE OF CONTENTS

PAGE

LIST OF FIGURES

PRECEDING PAGE BLANK-NOT FILMED

I. INTRODUCTION

The study of the physical properties of black powder and their influence on combustion has been a subject for continuing inquiry at the Ballistic Research Laboratory. One report on this subject was published in the proceedings of the Seventh International Pyrotechnics Seminar.[1a,b] In this earlier study black powder grains, prepared by the Army Ammunition Pilot Plant at Charlestown, IN, were evaluated and various physical properties were related to flame spread rates. It was concluded that the manufacturing procedure of compacting black powder meal produced considerable local plastic flow among particles, forming a conglomerate matrix of interconnecting passageways. Correlations between internal surface area, pore volume, and density were made with flame spread rates. These relationships and scanning electron microscopy, S.E.M., photographs, suggested that increasing the degree of openness of black powder grains increased burning rates.

In the present study,[2a,b] laboratory samples were compressed to provide a larger distribution of densities than had been previously available. Also, samples were prepared from a single batch of black powder meal, so that all samples were chemically identical. This approach insured that any observed difference in burning rate could be directly related to the degree of openness of the black powder grains. Samples were pressed into parallelepipeds, burned, and photographed. Because of this simple geometry, strand burn rates could be determined and related to densities. This is in contrast to earlier work in which flame spread rates among a collection of grains were related to various measurements of free volume.

Strands were burned and photographed using high-speed cinematography. From the images, burning rates were measured from atmospheric pressure to 100 atmospheres. These movies also show other combustion phemonena, including particle-droplet size and velocity. In the course of this research, the density of black powder was related to compaction pressure in the presence and absence of moisture. From these experiments, a detailed description of black powder evolved that should aid both the ballistician and manufacturer.

---

[1] *a. R.A. Sasse', "The Influence of Physical Properties of Black Powder on Burning Rate," Seventh International Pyrotechnics Seminar, Vol. 2, p. 536, IIT Research Institute, Chicago, IL, July 1980.*
b. R.A. Sasse', "The Influence of Physical Properties on Black Powder Combustion," AR BRL-TR-02308, Ballistic Research Laboratory, USA ARRADCOM, Aberdeen Proving Ground, MD, March 1981 (AD A100273).

[2] *a. R.A. Sasse', "Strand Burn Rates of Black Powder to One Hundred Atmospheres," Eighth International Pyrotechnics Seminar, p. 588, IIT Research Institute, Chicago, IL, July 1982.*
b. R.A. Sasse', "Strand Burn Rates of Black Powder to One Hundred Atmospheres," 19th JANNAF Combustion Meeting, CPIA Publication No. 366, Vol. I, p. 13, October 1982.

II. EXPERIMENTAL

A. Black Powder Samples

Black powder meals were supplied by the U.S. Army Ammunition Plant from its jet-mill pilot plant. Two meals were prepared; one contained maple and the other contained oak charcoal. The material was part of the meal originally prepared for the "deviant lot series"* described by Hugh Fitler[3] for a project supported by the Product Assurance Directorate.[4] During storage, the meal had conglomerated to some degree. Therefore, prior to use, it was re-ground using a mortar and pestle. Material was used which passed through a 120 mesh screen but not through a 200 mesh screen.

Dry meal requires a higher compaction pressure to yield a particular density than does moist meal. To avoid the difficulty of regulating both water content and compaction pressure, samples were pressed in a constant volume die where a spacer, which limited piston travel, controlled dimensions. Parallelepipeds (4x5x22 mm) were formed with a hydraulic press. This approach had the advantage of producing a series of samples of predictable densities by placing known weights of meal into the die. The samples exhibited some elasticity; their exact volumes and hence their densities were calculated from the measured dimensions of each sample.

B. Temperature Estimate

Some indication of temperature and heat propagation were obtained by imbedding a bare chromel-alumel thermocouple in the middle of black powder meal and then compressing the sample. The wires were 127 microns (0.005 in) in diameter, and they were made by the Omega Engineering Inc. of Stamford, CT. The measuring bead was three times the thickness of the wire.

C. Cinematography

High-speed 16-mm movies were taken with a Photec IV camera made by Photonic Systems, Inc., of Sunnyvale, CA. The camera was operated at 2000 frames per second and employed a F/2.5 shutter. Either a 100-mm or 50-mm lens was fitted to a 1.4-cm extension tube. Exposures were made at F/4.5. The subject was about 35 cm from the camera, and the image size was approximately one-quarter the size of the subject. Samples were illuminated by a 600-watt tungsten lamp focused by a 455-mm diameter spun aluminum paraboloid reflector. In some experiments, an Edgerton, Germeshousen and Grier (E.G.G.)

The deviant lot series were 10 lots of black powder prepared with small pertubations in constitutional composition, particle size or density.

[3]*H. Fitler, private communication, draft report, "Acceptance of Continously Produced Black Powder," ICI Americas Corp., Charlestown, IN, March 1979.*

[4]*J.C. Allen, "Scope of Work for MM & TE Project 5764303 Acceptance of Continuously Produced Black Powder," Report No. SARPA-QA-X-10, Picatinny Arsenal, Dover, NJ, November 1975.*

strobe light, model FX-2, was used for back lighting. Ektachrome high-speed movie film number 7242 having a 125 ASA tungsten rating was used as supplied by Eastman Kodak Co., Rochester, NY.

Above atmospheric pressure nitrogen was used to pre-pressurize a windowed chamber; the cell was of similar design to that made by Kubota.[5] In all cases, samples were ignited by a hot resistance wire.

III. RESULTS AND DISCUSSION

A. Compressing Black Powder Meal

In the manufacture of black powder, damp meal is pressed into a cake using various compaction pressures and different moisture contents to achieve a finished grain density of 1.7. The process was examined in detail by pressing meal slowly and recording the pressure and corresponding sample density as the pressure was increased. Samples of different moisture contents were evaluated.

Approximately two grams of meal were accurately weighed into the die. A known weight of water was placed on the powder surface to provide samples to 4 percent water. No mixing was attempted, and capillary action was presumed to soak the powder. The assembly was pressed, using an Instron Corp. material testing instrument, model 2TDM, made in Canton, MA. The small displacement rate of 0.254 mm per minute was selected, and a load of 3,000 g/cm^2 (40,000 psi) was applied slowly. Pressure history as a function of percent compaction, the ratio of sample height at a particular pressure to the original sample height, is given in Figure 1. Results are given for samples containing 0,1,2,3, and 4 percent water, and compaction functions are given by the set of parallel lines drawn in this figure. The observed parallelism suggests water is acting as a lubricant. The lines are not uniformly spaced, which could reflect that the samples did not have a uniform distribution of water.

The functional relationship between the logarithm of applied global pressure and compaction was suspected to be the result of compressing bounded spheres. This idea is supported by calculations of Knudsen[6] where he shows that the contact area between spheres is a linear function of porosity. To evaluate these concepts and assess the effect of particle size, two different sizes of nearly perfect copper spheres were individually compressed, using the same techniques as were employed with black powder meal. These spheres were of two diameters, 50 and 125 microns. Both diameter spheres gave the same

[5] *N. Kubota, T.J. Ohlemiller, L.H. Caveny, and M. Summerfield, "The Mechanism of Super-Rate Burning of Catalyzed Double Base Propellants," Report No. AMS 1087, Dept. of Aerospace and Mechanical Sciences, Princeton University, Princeton, NJ, March 1973.*

[6] *F.P. Knudsen, J. Am. Ceramic Soc., Vol. 42, No. 8, p. 376, August 1959.*

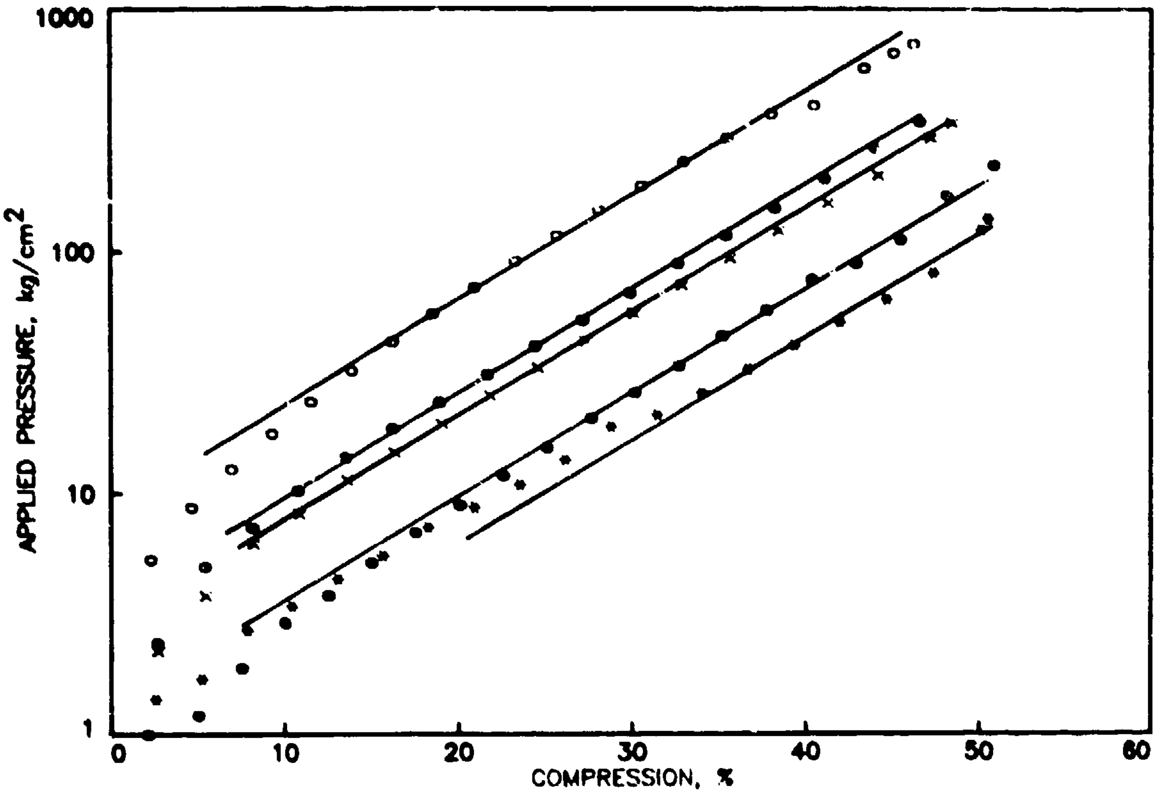

FIGURE 1. The Effect of Pressure on Black Powder Meal. 0, 0%; ●, 1%; +, 2%; ●, 3% and *, 4% water.

curve, which is shown in Figure 2. The early portion of the curve represents the movement of material to a close packed geometry, and the later portion of the curve represents plastic flow. These results suggest that different particle sizes do not influence grain density produced by a particular compaction pressure. The experiment also shows that compressing uniform size spheres results in a linear logarithmic relation of global pressure to the degree of compaction. These comments do not address combustion where particle size may be important. Had the compaction experiment been extended to greater pressures, the curves in Figure 2 would approach a vertical asymptote at 65 percent compaction where all voids would have been removed.

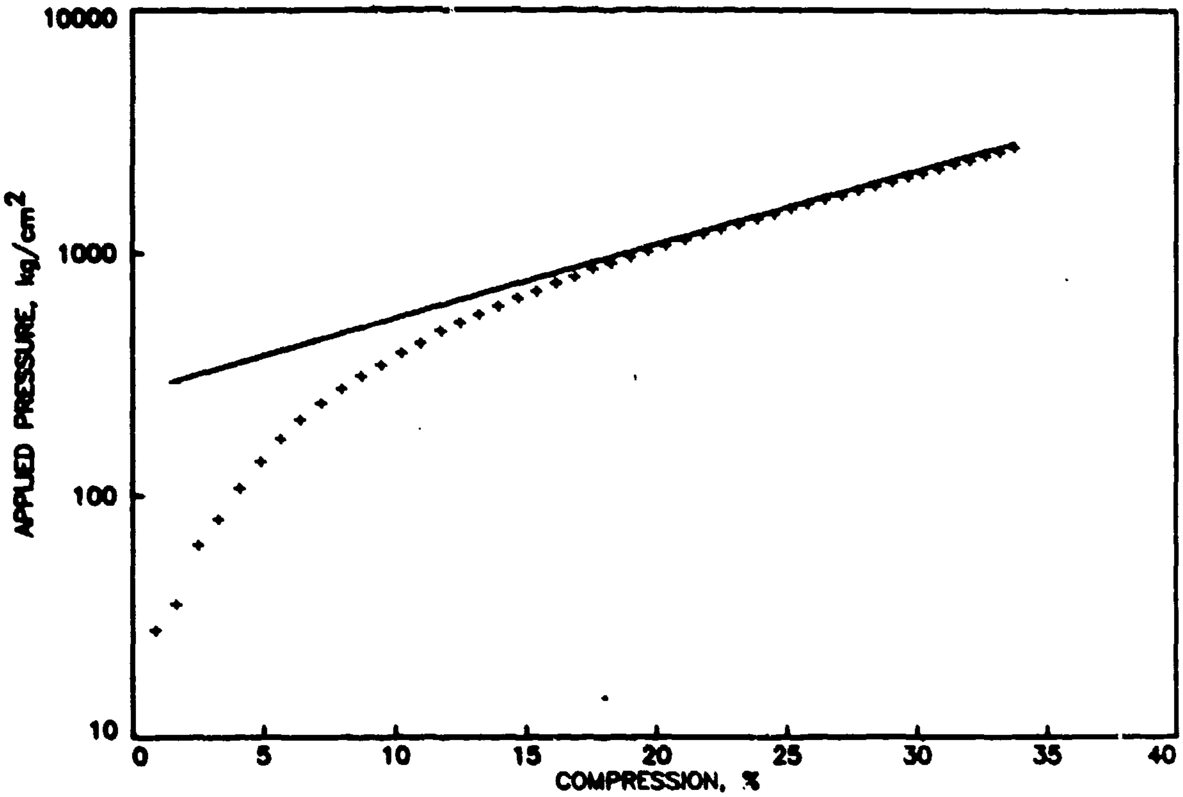

FIGURE 2. The Effect of Pressure on Copper Spheres of Different Diameters.

B Compressing Class One Black Powder Grains

Class one black powder grains are about the size of a pencil eraser; they are smaller than 4.76 and larger than 2.38 mm. They pass through a 4 but not an 8 standard mesh screen. Three grams of class one grains were placed in a die and compressed by the instron. Four different samples were evaluated:[1] Two were of fast burning material, deviant lots 10 and 11, and two were of slow burning material, deviant lots 1 and 6. At the start of the experiment, the die had a loading density of 1.07, and after compression black powder cylinders

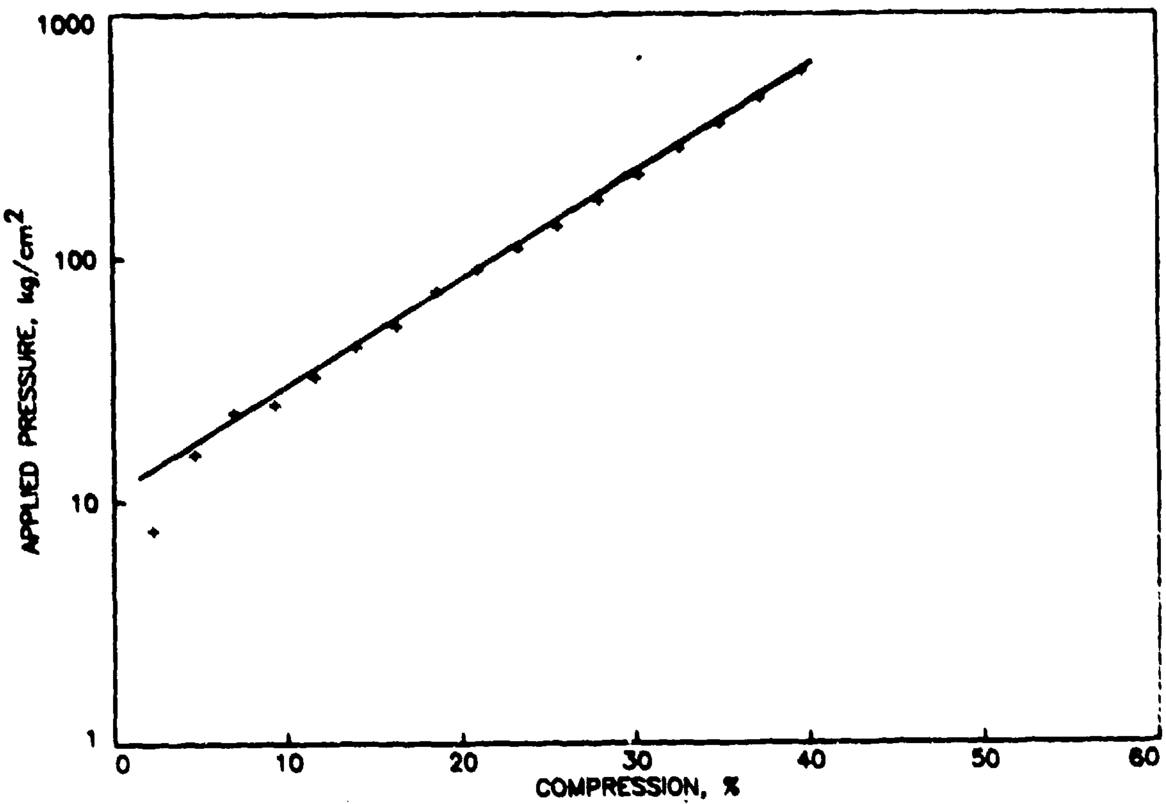

FIGURE 3. The Effect of Pressure on Class One Black Powder Grains.

having a density of 1.74 were removed from the die. This compression process is analogous to forming delay elements in various ammunitions. The results, given in Figure 4, exhibit the effect of global pressure on black powder grains. The four samples gave curves that can be superimposed on each other. The original densities were 1.63, 1.67, 1.86, and 1.78, but such density differences do not differentiate the curves one from another. That a logarithmic function again fits the data and the data were continuous indicate that applied pressure results in plastic flow between particles in the black powder grain. The experiment also shows that the grains do not break or crush before they become compacted. Moreover, the compaction curve for these large grains is similar to that obtained for dry meal, Figure 1; thus, this size difference does not affect plastic flow.

Considering the three types of compaction experiments discussed, it appears that plastic flow is the dominant process. The functional relationship between the logarithm of applied global pressure to percent compaction seems to be the result of compressing bounded spheres as inferred

from the copper experiments. This same relationship appears when compressing small particle size meal or large black powder grains. Considering the size difference between black powder meal and black powder grains and the two different radii of the copper spheres, it is suggested that the original particle size has little effect on the final density resulting from applying a particular global pressure.

C. Atmospheric Surface Burn Rates

Several uninhibited black powder parallelepiped samples of different densities were burned in air and photographed by high-speed cinematography. The surface burn rates were faster than the bulk rate, resulting in the evolution of a burning pyramid, the sides of which became steeper as combustion progressed. Gas plumes were formed normal to the burning surface, and thus four distinct gas jets were directed outward.

The location of the burning front moving down the strand was measured on successive films frames, and the position histories of this interface were plotted. Straight lines were drawn, and their slopes were taken as the burn rate. Results are given in Figure 4.

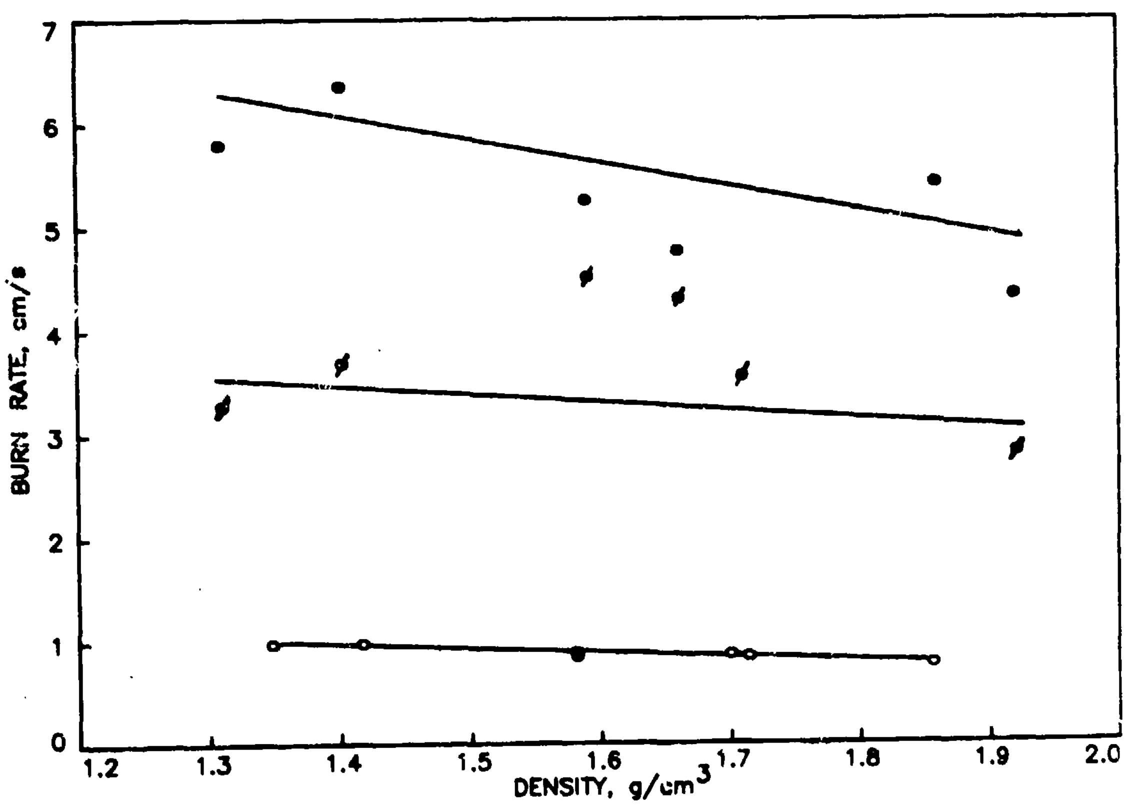

FIGURE 4. Combustion Rate as a Function of Density.
ϕ burn rate of surface made by moveable piston
● burn rate of surface made by die
0 strand burn rate

Several samples were evaluated. It soon became apparent that of the two surfaces viewed, one was burning faster than the other. It was found that the surface near the moveable die face was burning slower than the other surfaces. A clear correlation is shown relating these surface burn rates to density. For comparison, the strand burning rates, to be discussed in the next section, D, are also shown in this figure.

To measure the density distribution in a sample, George Thomson and Keith Jameson, of the Ballistic Modeling Division of BRL, used a 2.2 MeV proton beam produced by a Van de Graaff accelerator. The beam impinged upon a silver target to produce mono-energetic K edge X-rays. The analyzing beam was 1.2 mm in diameter and traversed the sample in successive steps. A larger sample was examined than was normally prepared to emphase density differences. Results are shown in Figure 5 where a sharp density increase was noted as the surface by the moveable die face was approached. This experiment confirms that a density distribution exists in laboratory pressed black powder samples, the severity of which will depend on die dimensions and pressing conditions.

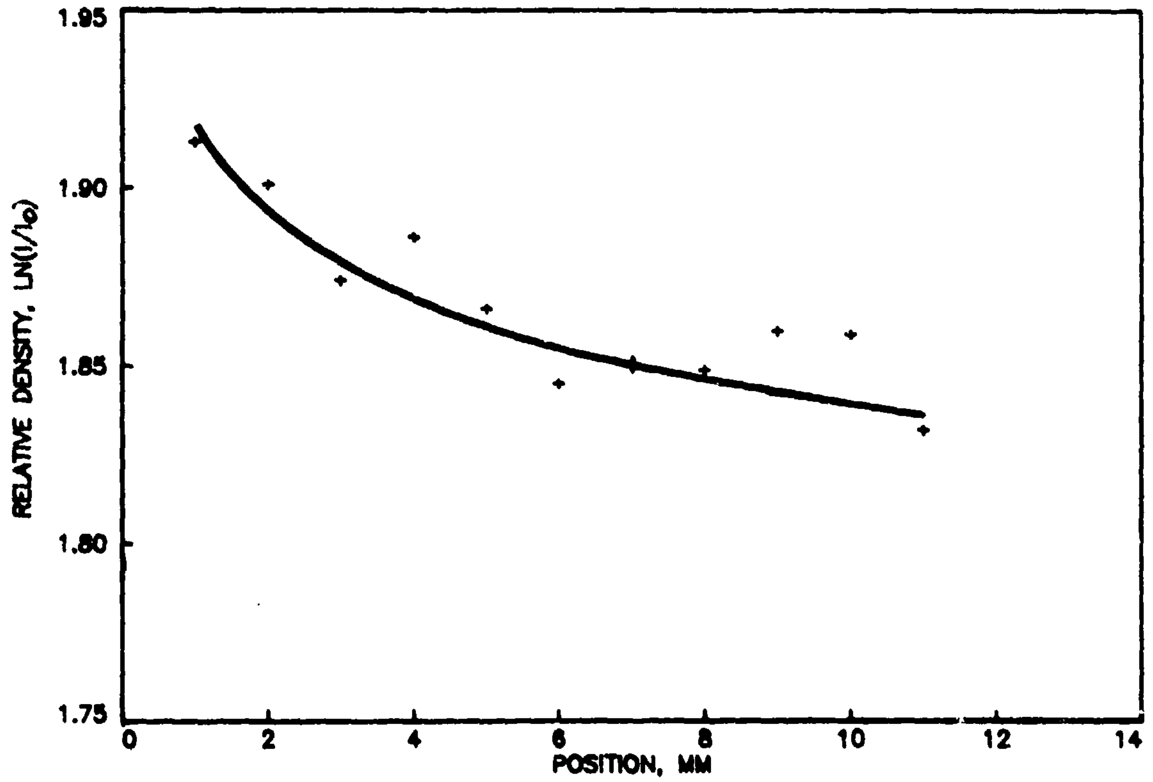

Figure 5. Relative Density as a Function of Distance along a Black Powder Strand. Position 0 Was the Surface Made by Moveable Die Face.

D. Atmospheric Strand Burning Rates

Kevin White of the BRL has performed micro-cinematography on graphite coated class one black powder grains, and he noted that during combustion the sample burns like a cigarette.[7] This implies graphite is an inhibitor. Such a coating of a GCKX deviant lot 11 sample was measured to be 6 microns thick by S.E.M. techniques. Thus, an inhibited sample is a proper analog to class one black powder. Such samples were prepared and inhibited with a coating of cyanoacrylate-based glue; they were burned in air and photographed. Burning rates were measured and the results are shown in Figure 6, which shows burning rates as a linear function of density for both oak and maple black powders. The standard deviation of the slope was taken as the error of measurement; these estimates are shown as error bars on the data points.

One additional experiment was performed to compare the burning rate of two sticks of black powder made to equal densities where one was pressed wet at low pressure and the other stick was prepared dry using higher pressures. Both samples were dried, and the burning rates were found to be equal. In

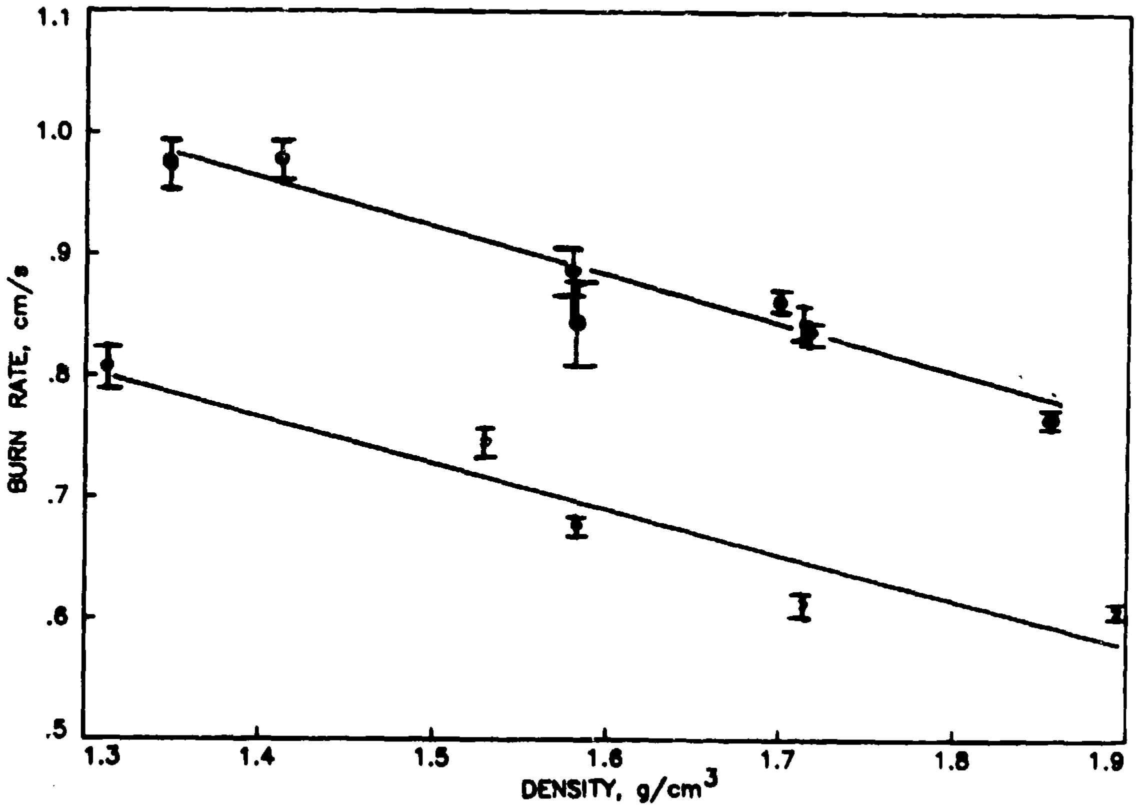

FIGURE 6. Strand Burn Rates at Atmospheric Pressure as a Function of Density. ● maple and O oak.

---

[7] *K. White, private communication, 1978.*

effect, the samples did not reflect their different preparation histories. An example of the cinematography is the reproduction of one of the 16-mm frames in Figure 7. The picture includes the strand of black powder, ignition wire, and helical spring contacts. The flat burning surface is evident as are a preponderance of both small and large particles. The larger particles were measured by Nathan Klein[8] of the BRL using a Quantimet 720 Image Analyzer made by Image Analyzing Computers, Inc.

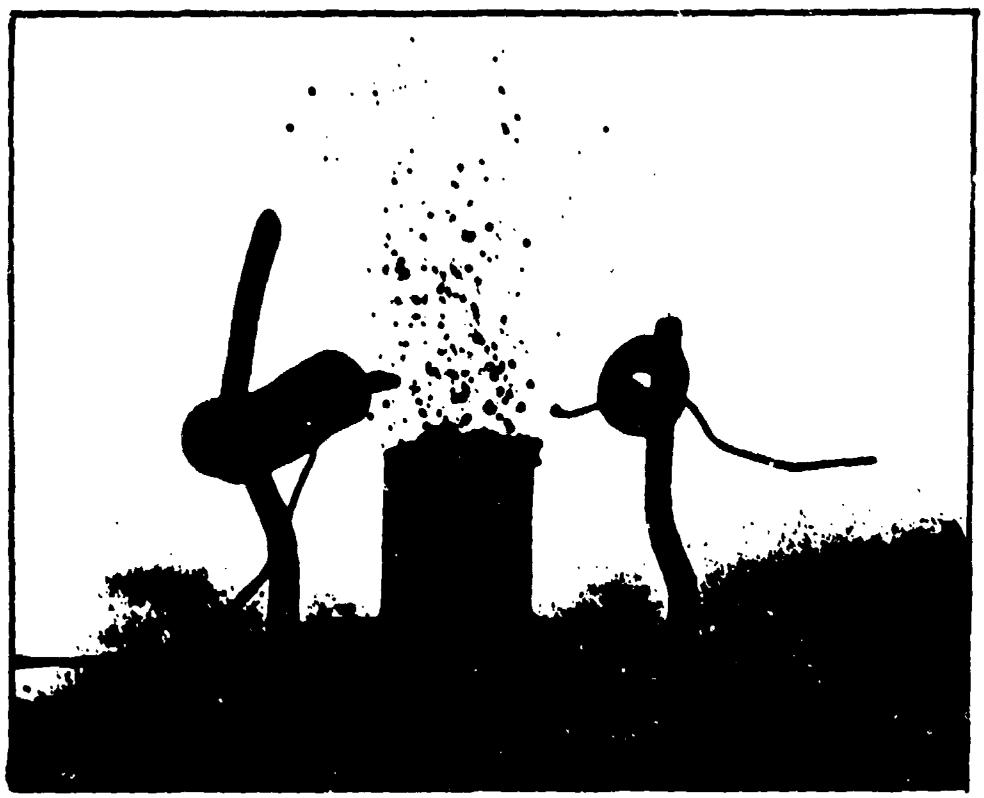

FIGURE 7. Enlarged Picture of 16-mm High-Speed Film Showing Burning Black Powder.

The distributions of both the length and breadth of the particles are given in Figure 8, and the similar distribution of these two parameters indicates that the particles are spherical and have a mean diameter of 280 microns. Particle velocity was also measured, and a value of 130 cm/sec was obtained.

The particles were collected on a fine 50 mesh screen and examined with 70x stereomicroscope. They appeared as perfect, smooth spheres of the various colors of white, black, and yellow-striped spherical bodies. In the absence of contrary evidence, these spheres are suggested to be frozen droplets of nonreactive molten black powder blown from the burning surface. In addition,

---

[8] *N. Klein, "The Use of Holography in Combustion Diagnostics," draft report.*

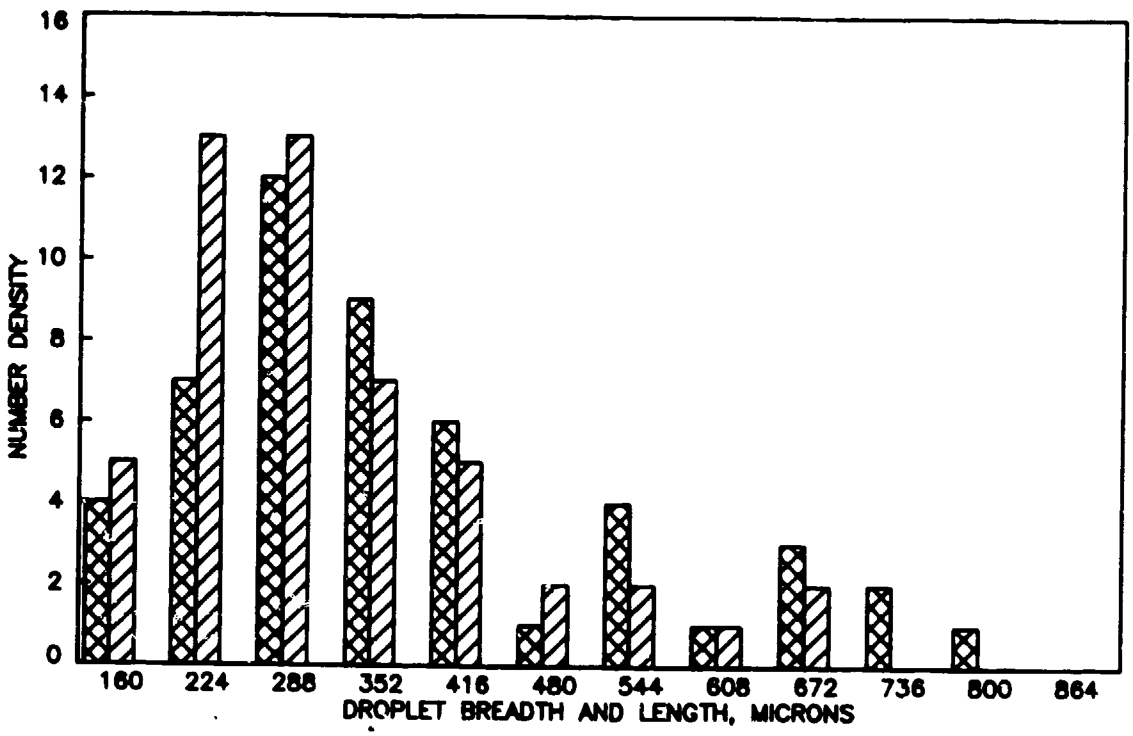

FIGURE 8. Large Particle Size Distribution. [crosshatched box] length and [hatched box] breadth.

a fine dust was collected on a polished surface and examined with S.E.M. techniques. The dust appeared as particles between 0.4 and 1.0 microns in size; they had sharp edges protruding from a porous irregular structure. They are believed to be the result of condensation of reaction products. Only chemical analysis can verify the nature and origin of these particles.

E. Thermocouple Measurements

Thermocouple temperature measurements are clearly suspect, due to various heat losses, but an experiment was attempted to form a lower bound estimate of how deeply heat penetrated a porous sample of black powder. In a broader sense the experiment was attempted to determine if the thermocouple would respond in a compressed salt matrix. The measurement was performed by placing a thin chromel-alumel thermocouple into the center of black powder meal, and compressing the unit. The sample was burned in air and the output signal, referenced to an ice-water junction, was recorded on a digital oscilloscope. Results are given in Figure 9 where zero time was arbitrarily set; also, the early temperature, ca 100°C, was not deemed significant. During combustion, at a burning rate of one cm per second, the temperature increased to 480°C in 2.2 ms before the thermocouple was exposed to the gas stream. This is a lower bound estimate of the temperature of the liquid layer, and the gas temperature, represented by the vertical asymptote, could not be measured by this type of thermocouple.

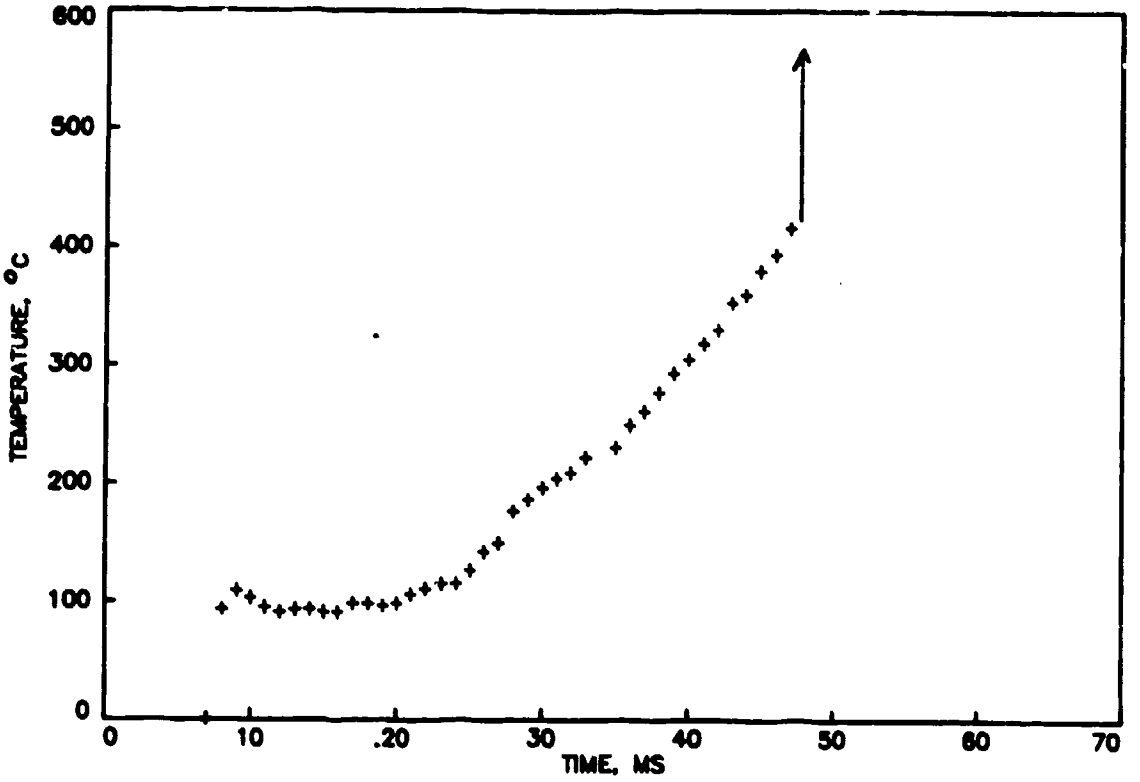

FIGURE 9. Temperature of Thermocouple in Burning Black Powder as a Function of Time.

The value of 480°C agrees well with the measurement made by Lenchitz and Hayes[9] of 469±50°C for ignition temperature using arc image techniques. It would appear that the small mass of this thermocouple and the large heat source of the combustion front contribute to a fair estimate of the temperature of the liquid layer. From the burning rate and time-temperature relationship, the heat penetrated about 220 microns below the combustion-gas interface. From these relationships the thermocouple appears too thick to make an accurate or even fair measurement of the depth of the heat penetration, but the experiment establishes that the heated zone is thin and smaller than 220 microns.

---

[9] *C. Lenchitz and E. Hayes, 16th JANNAF Combustion Meeting, CPIA Publication No. 308, Vol. 3, p. 169, December 1979.*

F. High-Pressure Strand Burn Rates

Inhibited maple black powder samples were burned and photographed in a windowed chamber in an atmosphere of flowing nitrogen. Pairs of samples, one of high density and the other of low density, were evaluated at several different pressures to 100 atmospheres. To reduce the obscuration effects of smoke, the optical path inside the chamber was reduced to 8 mm by inserting two plastic spacers. Results are presented in Figure 10 and Table 1, where it is seen that only a small difference in burning rate can be ascribed to different density samples at a particular pressure. This close correspondence

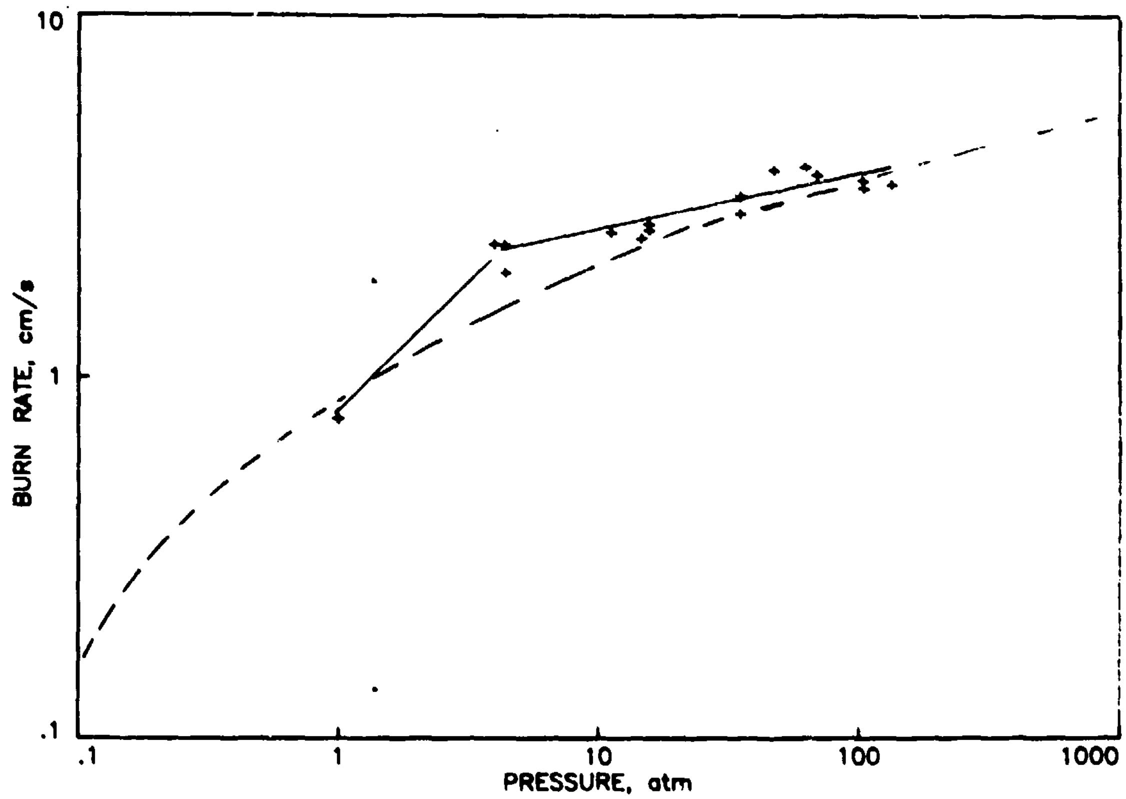

FIGURE 10. Strand Burn Rates at High Pressures. Dashed line Reference 10.

TABLE I. HIGH-PRESSURE STRAND BURN RATES

Pressure atm	Density g/cm^3	Burn Rate cm/sec	Pressure atm	Density g/cm^3	Burn Rate cm/sec
133.6	1.42	5.10	15.6	1.48	2.55
133.6	1.70	3.41	15.6	1.67	2.65
103.7	1.91	3.50	14.6	1.83	2.42
104.4	1.65	3.33	11.2	1.66	2.51
69.0	1.64	3.63	4.40	1.67	2.32
62.2	1.55	3.82	4.40	1.83	1.94
47.3	1.70	3.75	4.40	1.64	2.32
35.0	1.68	3.18	1.00	1.88	0.733
35.0	1.85	2.84	1.00	1.55	0.768

was noted over the entire pressure range. The data contain some scatter and values are compared to the average response curve derived from several Russian references summarized by Williams[10] using the data of Belyaev and Maznev,[11] Glaskova and Tereshkin,[12] and Belyaev et al.[13] The excellent agreement among the various studies is surprising, considering that different charcoals and different preparation procedures were used. In fact, one reason for undertaking strand burn rate measurements was to relate results to samples that were described in as much detail as possible. The burn rate function, or more precisely, the sample regression rate, r, (cm/sec) and pressure, p,

---

[10] *F.A. Williams, <u>AIAA Journal</u>, Vol. 14, No. 5, p. 367, May 1976.*

[11] *A.F. Belyaev and S.F. Maznev, "Dependence of Burning Rate of Smoke-Forming Powder on Pressure," <u>Dokl. Akad. Nauk SSSR</u>, Vol. 131, p. 887, 1960.*

[12] *A.P. Glazkova and I.A. Tereshkin, "Relation Between Pressure and Burning Velocity of Explosives," <u>Zhur. Fiz. Khim.</u>, Vol. 35, pp. 1622-1628, 1961.*

[13] *A.F. Belyaev, A.I. Korotkov, A.K. Parfenov and A.A. Sulimov, "The Burning Rate of Some Explosive Substances and Mixtures at Very High Pressures," <u>Zhur. Fiz. Khim.</u>, Vol. 37, p. 150, 1963.*

(atm), was evaluated for pressures between 3 to 100 atmospheres. The relationship

$$r = 1.72\ p^{(0.164 \pm 0.017)} \quad (1)$$

was obtained.

The burn rate curves of this and other referenced work exhibit a sharp change in slope at pressures of a few atmospheres. Cinematography was used to see if a different mode of combustion, such as deconsolidation, was associated with this transition, and no change was observed. The only difference noted was that at low pressure the cell had a carbonaceous deposit on the chamber walls, whereas in high-pressure experiments large droplets were observed. However, the films all looked much alike.

These burning rates were compared by K. White[14] to the closed bomb data of Price, and an extensive discussion evolved suggesting that burn rate equations derived from closed bomb experiments are different from strand burning rate equations. Such differences were suggested to originate from either grain breakup or porous burning. Presently we are investigating this phenomenon further by burning single strands in either a small rocket motor or a closed bomb. Preliminary results give the same burning rates as reported in Table 1, indicating that porous burning or deconsolidation is not occurring. By induction, the data discussed by K. White appear to be the result of grain breakup, and future work should be directed to document such effects.

IV. GENERAL COMMENTS

Several experiments have been presented to describe the compaction process in terms of plastic flow and the overall effect of compaction in terms of density and its corresponding burning rate. Strand and surface burning rates have been shown to be functions of density; however, the dependency is small, about 20 percent. Such differences are greatly amplified in grain-to-grain flame spread rates that can vary over this density range by 200 percent as do relative quickness values. Such differences have been previously pointed out,[14] but it is this difference that may be closely related with device performance. The density of black powder has been used as a variable to relate various parameters discussed in this report. However, as pointed out in an earlier work,[1], this quantity is another view of pore volume and internal surface area. One of the important parameters that affects the free volume of black powder is that lot-to-lot samples of charcoal have different densities, and this variance can affect the degrees of porosity of black powder (at a given density) without changing the constitutional composition of potassium nitrate, sulfur and charcoal. Such information is not generally available from either charcoal manufacturer or black powder producer, and it would seem advantageous to make such measurements. It is possible that the organic content of charcoal, so often reported as affecting response, is proportional to its density. This author is guided by A. Kirshenbaum's

[14] *K. White and R. Sasse', "Combustion and Flame Characteristics of Black Powder," 18th JANNAF Combustion Meeting, CPIA Publication No. 347, Vol. 2, p. 253, October 1981.*

comments[15] that ignition temperature of several samples was increased as volatiles were removed; however, these volatile-free samples' ignition temperatures still retained their original rank. Kirshenbaum suggested that some property beyond volatile content affects ignition temperature.

The question of "organics" in charcoal and their relative contribution to combustion has been a subject of continuing study. Not the first, but a fine example of such work is the paper by Hintze[16] showing a maximum in burning rate of black powder occurs at about 30% organic content in charcoal. This value was used in duPont purchasing specification since 1930, and is part of a gentleman's agreement for the purchase of charcoal. Inclusion of this parameter into the military specification for charcoal is long overdue. Such a position also appears to be supported by Robertson's[17] paper as inferred from his abstract of the work. (The paper was not available at the time of this writing.) Additionally, the importance of organics in black powder was demonstrated[18] by using black powder made by the total substitution of charcoal by various reducible organic compounds containing hydroxyl groups. Similar burning rates to black powder were measured for several mixtures. It appears there is nothing unique about charcoal with respect to the combustion of KNO_3 mixtures.

The above discourse on "organics" promotes several additional comments on other problem areas where such thoughts are my speculations that have been sharpened over a two-year period. The first reflections concern charcoal and contrast the jet mill Lovold process to the duPont wheel mill product.

The duPont process grinds large quantities of feed stock in amounts that approach 3,000 pounds. This single batch processing insures a great averaging of the properties of individual bags of charcoal. In the more continuous jet mill process, such differences in the input material may become apparent in the black powder product. Under these circumstances it would appear prudent to test the charcoal such that a uniform material is employed. Some degree of characterization could be accomplished by analytical tests that would at least bracket global properties. Some tests are listed below. Earlier in 1975,

---

[15] *A. Kirshenbaum, Thermochimica Acta, Vol. 18, p. 113, 1977.*

[16] *W. Hintze, Explosivstoffe, Vol. 2, p. 41, 1968.*

[17] *J. Robertson, "The Influence of Charcoal in the Combustion of Black Powder," RARDE, Fort Halstead, Sevenoaks, England. Presented at Basic and Applied Pyrotechnic's International Conference, ARCACHON, France, October 1982.*

[18] *S. Wise and R.A. Sasse', "Organic Substitutes for Charcoal in "Black Powder" Type Pyrotechnic Formulations," 19th JANNAF Combustion Meeting, CPIA Publication No. 366, Vol. 2, p. 305, October 1982.*

Rose[19] made similar comments in a short but illuminating paper on black powder.

Analysis of Charcoal:
1. Analysis for carbon, hydrogen, oxygen
2. Heat of combustion
3. Percent volatiles
4. True density.

Such characterization would form a baseline such that the same quality black powder could be produced again. More important, such data could be correlated to functional performance and be the basis for a comprehensive military specification for charcoal.

Black powder itself should also be characterized further by tests that recognize that "as chemistry influences combustion, so do the physical properties of the material." Such tests could include:

Analysis of Black Powder:
1. Combustion tests (flame spread etc.)
2. Performance related tests (gun)
3. True and bulk densities
4. Internal surface area (B.E.T.)
5. Grain size distribution.

Another area of concern is related to pressing meal to produce a black powder "cake." In the DuPont-GOEX press pressure is applied slowly and applies force over a time period of 15-20 minutes such that plastic flow may reach equilibrium or steady-state. In contrast, in the jet mill process the press will exert force for less than one minute. In both cases a density distribution will occur thoughout the samples cross section, and perhaps a sharper distribution will occur in the latter instance. The physical processes which are both geometry and time dependent that are operative during pressing meal are not clear. For instance, in a closed die the friction between the die wall and sample will lead to a density distribution.[20] This effect will lead to a redistribution of water within the sample which compounds density differences. Dynamic effects could further enhance the problem. Even in the many large, 720 X 24 X 1 inch, thick slabs made by GOEX, a small density distribution is observed, and this difference is induced even in a large open sided die where pressing is done in three incremental steps as more meal is added. The total problem of distribution appears too complex for analysis and it would be better to measure the density distribution of a

---

[19] *J.E. Rose, "Investigation on Black Powder and Charcoal," IHTR-433, September 1975, Naval Ordance Station, Indian Head, MD, October 1982.*

[20] *L.O. Burchett, "PRESS: A Computer Program For Evaluating Explosive Material Loading Processes," Eighth International Pyrotechnics Seminar, p. 991, IIT Research Institute, Chicago, IL, July 1982.*

"cake" produced in a particular way. If the density extremes are significant within the "cake," then such differences would greatly influence combustion.

The functional tests described should characterize both charcoal and black powder such that different lots can be compared in relation to their physical as well as chemical properties. Such data, together with performance evaluations, could lead to more realistic military specifications. In this "general comments section" concern should be restated on a major topic of this paper, namely, the comparison of strand and closed bomb burn rate data. Differences in combustion rate were speculated to originate from grain break-up and if this be true then structural-strength of black powder will be an important parameter in understanding combustion. This type of information is required to assure proper performance and assure sound testing procedures. These differences in burn rates should be resolved.

V. CONCLUSIONS

The object of the present work was to make a more reproducible black powder and to remove some of the mysticism associated with its manufacture. Insight into compaction and how the process affected the strand burning rate at high and low pressures is presented. The mode of combustion seems invariant to pressures of 100 atmospheres. Results confirm the earlier observation that the burning rate is directly related to the degree of openness of a black powder grain.

ACKNOWLEDGEMENTS

Assistance from several people from the BRL was required to complete this study, and I thank Kevin White who has worked beside me and has been principal author on several black powder flame propagation studies. Eli Freedman's advice and evaluation of the thermodynamics of black powder systems has provided insight into black powder systems. Several experiments were performed by Gould Gibbons, Jr., Nathan Klein, Dominick DiBerardo, Timothy Brosseau, George Thomson and Keith Jamison.

REFERENCES

1. a. R.A. Sasse', "The Influence of Physical Properties of Black Powder on Burning Rate," Seventh International Pyrotechnics Seminar, Vol. 2, p. 536, IIT Research Institute, Chicago, IL, July 1980.
b. R.A. Sasse', "The Influence of Physical Properties on Black Powder Combustion," AR BRL-TR-02308, Ballistic Research Laboratory, USA ARRADCOM, Aberdeen Proving Ground, MD, March 1981 (AD A100273).

2. a. R.A. Sasse', "Strand Burn Rates of Black Powder to One Hundred Atmospheres," Eighth International Pyrotechnics Seminar, p. 588, IIT Research Institute, Chicago, IL, July 1982.
b. R.A. Sasse', "Strand Burn Rates of Black Powder to One Hundred Atmospheres," 19th JANNNAF Combustion Meeting, CPIA Publication No. 366, Vol. I, p. 13, October 1982.

3. H. Fitler, private communication, draft report, "Acceptance of Continuously Produced Black Powder," ICI Americas Corp., Charlestown, IN, March 1979.

4. J.C. Allen, "Scope of Work for MM & TE Project 5764303, Acceptance of Continuously Produced Black Powder," Report No. SARPA-QA-X-10, Picatinny Arsenal, Dover, NJ, November 1975.

5. N. Kubota,, T.J. Ohlemiller, L.H. Caveny, and M. Summerfield, "The Mechanism of Super-Rate Burning of Catalyzed Double Base Propellants," Report No. AMS 1087, Dept. of Aerospace and Mechanical Sciences, Princeton University, Princeton, NJ, March 1973.

6. F.P. Knudsen, J. Am. Ceramic Soc., Vol. 42, No. 8, p. 376, Aug. 1959.

7. K. White, private communication, 1978.

8. N. Klein, "The Use of Holography in Combustion Diagnostics," draft report.

9. C. Lenchitz and E. Hayes, 16th JANNAF Combustion Meeting, CPIA Publication No. 308, Vol. 3, p. 169, December 1979.

10. F.A. Williams, AIAA Journal, Vol. 14, No. 5, p. 367, May 1976.

11. A.F. Belyaev and S.F. Maznev, "Dependence of Burning Rate of Smoke-Forming Powder on Pressure," Dokl. Akad. Nauk SSSR, Vol. 131, p. 887, 1960.

12. A.P. Glazkova and I.A. Tereshkin, "Relation Between Pressure and Burning Velocity of Explosives," Zhur. Fiz. Khim., Vol. 35, pp. 1622-1628, 1961.

13. A.F. Belyaev, A.I. Korotkov, A.K. Parfenov, and A.A. Sulimov, "The Burning Rate of Some Explosive Substances and Mixtures at Very High Pressures," Zhur. Fiz. Khim., Vol. 37, p. 150, 1963.

REFERENCES

14. K. White and R.A. Sasse', "Combustion and Flame Characteristics of Black Powder," 18th JANNAF Combustion Meeting, CPIA Publication No. 347, Vol. 2, p. 253, October 1981.

15. A. Kirshenbaum, Thermochimica Acta, Vol. 18, p. 113, 1977.

16. W. Hintze, Explosivstoffe, Vol. 2, p. 41, 1968.

17. J. Robertson, "The Influence of Charcoal in the Combustion of Black Powder," RARDE, Fort Halstead, Sevenoaks, England. Presented at Basic and Applied Pyrotechnic's International Conference, ARCACHON, France, October 1982.

18. S. Wise and R.A. Sasse', "Organic Substitutes for Charcoal in "Black Powder" Type Pyrotechnic Formulations," 19th JANNAF Combustion Meeting, CPIA Publication No. 366, Vol. 2, p. 305, October 1982.

19. J.E. Rose, "Investigation on Black Powder and Charcoal," IHTR-433, September 1975, Naval Ordnance Station, Indian Head, MD, October 1982.

20. L.O. Burchett, "PRESS: A Computer Program for Evaluating Explosive Material Loading Processes," Eighth International Pyrotechnics Seminar, p. 991, IIT Research Institute, Chicago, IL, July 1982.

DISTRIBUTION LIST

No. Of Copies	Organization
12	Administrator Defense Technical Info Center ATTN: DTIC-DDA Cameron Station Alexandria, VA 22314
1	Commander USA DARCOM ATTN: DRCDMD-ST 5001 Eisenhower Avenue Alexandria, VA 22333
1	Commander USA ARRADCOM ATTN: DRDAR-TDC D. Gyorog Dover, NJ 07801
2	Commander USA ARRADCOM ATTN: DRDAR-TSS Dover, NJ 07801
3	Commander USA ARRCOM ATTN: DRSAR-LEP-L DRSAR-IRC, C.H. Cowan DRSAR-LEM, R. Freedman Rock Island, IL 61299
1	Director USA ARRADCOM Benet Weapons Laboratory ATTN: DRDAR-LCB-TL Watervliet, NY 12189
1	Commander USA Aviation Research and Development Command ATTN: DRDAV-E 4300 Goodfellow Blvd. St. Louis, MO 63120
1	Director USA Air Mobility Research and Development Laboratory Ames Research Center Moffett Field, CA 94035
4	Commander US Army Research Office ATTN: R. Girardelli D. Mann R. Singleton D. Squire Research Triangle Park, NC 27709
1	Commander USA Communications Research and Development Command ATTN: DRSEL-ATDD Fort Monmouth, NJ 07703
1	Commander USA Electronics Research and Development Command Technical Support Activity ATTN: DELSD-L Fort Monmouth, NJ 07703
10	Commander USA ARRADCOM ATTN: DRDAR-LCA-G, D.S. Downs J.A. Lannon K. Russel W. Voight J.P. Picard H. Gultz R. Collins H. Mitsuguma A. Smetana D. Hanson Dover, NJ 07801
2	Commander USA ARRADCOM ATTN: DRDAR-LC, L. Harris DRDAR-SCA-T, L. Stiefel Dover, NJ 07801
2	Commandant US Army Infantry School ATTN: ATSH-CD-CSO-OR Fort Benning, GA 31905

DISTRIBUTION LIST

No. Of Copies	Organization	No. Of Copies	Organization
1	Commander USA Missile Command ATTN: DRSMI-R Redstone Arsenal, AL 35898	4	Commanding Officer Naval Ordnance Station ATTN: C. Irish S. Mitchell J. Rose P.L. Stang, Code 515 Indian Head, MD 20640
1	Commander USA Missile Command ATTN: DRSMI-YDL Redstone Arsenal, AL 35898	1	Commander Naval Surface Weapons Center ATTN: J.L. East, Jr., G-20 Dahlgren, VA 22448
1	Commander USA Missile Command ATTN: DRSMI-RK, D.J. Ifshin Redstone Arsenal, AL 35898	1	Commander Naval Surface Weapons Center ATTN: G.B. Wilmot, R-16 Silver Spring, MD 20910
1	Commander USA Tank Automotive Command ATTN: DRSTA-TSL Warren, MI 48090	4	Commander Naval Weapons Center ATTN: R.L. Derr, Code 388 China Lake, CA 93555
1	Director USA TRADOC System Analysis Activity ATTN: ATAA-SL WSMR, NM 88002	1	Commander Naval Weapons Center ATTN: T. Boggs China Lake, CA 93555
1	Office of Naval Research ATTN: R.S. Miller, Code 432 800 N. Quincy Street Arlington, VA 22217	1	Superintendent Naval Postgraduate School Dept. of Aeronautics ATTN: D. W. Netzer Monterey, CA 93940
1	Navy Strategic Systems Project Office ATTN: R.D. Kinert, SP 2731 Washington, DC 20376	1	Commanding Officer Naval Underwater Systems Center Weapons Dept. ATTN: R.S. Lazar/Code 36301 Newport, RI 02840
1	Commander Naval Air Systems Command ATTN: J. Ramnarace, AIR-54111C Washington, DC 20360		

DISTRIBUTION LIST

No. Of Copies	Organization
6	AFRPL (DRSC) ATTN: R. Geisler D. George B. Goshgarian J. Levine W. Roe D. Weaver Edwards AFB, CA 93523
1	AFATL/DLDL ATTN: O.K. Heiney Eglin AFB, FL 32542
1	AFOSR ATTN: L.H. Caveny Bolling Air Force Base Washington, DC 20332
1	NASA Langley Research Center ATTN: G.B. Northam/MS 168 Hampton, VA 23365
5	National Bureau of Standards ATTN: J. Hastie M. Jacox T. Kashiwagi H. Semerjian J. Stevenson Washington, DC 20234
1	Aerojet Solid Propulsion Co. ATTN: P. Micheli Sacramento, CA 95813
1	Applied Combustion Technology, Inc. ATTN: A.M. Varney 2910 N. Orange Avenue Orlando, FL 32804
2	Atlantic Research Corp. ATTN: M.K. King 5390 Cherokee Avenue Alexandria, VA 22314
1	Atlantic Research Corp. ATTN: R.H.W. Waesche 7511 Wellington Road Gainesville, VA 22065
1	AVCO Everett Rsch. Lab. Div. ATTN: D. Stickler 2385 Revere Beach Parkway Everett, MA 02149
1	Battelle-Columbus Labs Tactical Technology Center ATTN: J. Huggins 505 King Avenue Columbus, OH 43201
1	Calspan Corporation ATTN: E.B. Fisher P.O. Box 400 Buffalo, NY 14225
1	Estes Industries ATTN: E. Brown Penrose, CO 81240
2	Exxon Research & Engineering Co. ATTN: A. Dean M. Chou P.O. Box 45 Linden, NJ 07036
1	Ford Aerospace and Communications Corp. DIVAD Division Div. Hq., Irvine ATTN: D. Williams Main Street & Ford Road Newport Beach, CA 92663
1	General Electric Armament & Electrical Systems ATTN: M.J. Bulman Lakeside Avenue Burlington, VT 05402
1	General Electric Company ATTN: M. Lapp Schenectady, NY 12301

DISTRIBUTION LIST

No. Of Copies	Organization
1	General Electric Ordnance Systems ATTN: J. Mandzy 100 Plastics Avenue Pittsfield, MA 01203
1	General Motors Rsch Labs Physics Department ATTN: J.H. Bechtel Warren, MI 48090
2	GOEX Inc. ATTN: F. Fahringer Belin Plant Moosic, PA 18507
2	GOEX Inc. ATTN: David Levey Route 3, Box 423 Cleburne, TX 76031
3	Hercules, Inc. Allegheny Ballistcs Lab ATTN: R.R. Miller P.O. Box 210 Cumberland, MD 21501
3	Hercules, Inc. Bacchus Works ATTN: K.P. McCarty P.O. Box 98 Magna, UT 84044
1	Hercules, Inc. AFATL/DLDL ATTN: R.L. Simmons Eglin AFB, FL 32542
1	Honeywell, Inc. Defense Systems Division ATTN: D.E. Broden/ MS MN50-2000 600 2nd Street NE Hopkins, MN 55343
1	IBM Corporation ATTN: A.C. Tam Research Division 5600 Cottle Road San Jose, CA 95193
4	ICI Americas Inc. Indiana Army Ammunition Plant ATTN: R. Shultz G. Mcloskey H. Hill G. Everson Charlestown, IN 47111
2	ICI Americas Inc. Central Engineering Department ATTN: W. Brill D. Bundas Wilmington, DE 19897
1	Lawrence Livermore National Laboratory ATTN: C. Westbrook Livermore, CA 94550
1	Lockheed Palo Alto Rsch Lab ATTN: George Lo 3251 Hanover Street Dept. 52-35/B204/2 Palo Alto, CA 94304
1	Los Alamos National Lab ATTN: B. Nichols T7, MS-B284 P.O. Box 1663 Los Alamos, NM 87545
1	Paul Gough Associates, Inc. ATTN: P. S. Gough P.O. Box 1614 Portsmouth, NH 03801
1	Olin Corporation Smokeless Powder Operations ATTN: R.L. Cook P.O. Box 222 St. Marks, FL 32355

DISTRIBUTION LIST

No. Of Copies	Organization
2	Princeton Combustion Research Laboratories ATTN: M. Summerfield N.A. Messina 1041 US Highway One North Princeton, NJ 08540
1	Pulsepower Systems, Inc. ATTN: L.C. Elmore 815 American Street San Carlos, CA 94070
1	Pyrodex Corporation ATTN: D. Barrett P.O. Box 2905 Shawnee Mission, KS 66202
1	Rockwell International Corp. Rocketdyne Division ATTN: J.E. Flanagan/HB02 6633 Canoga Avenue Canoga Park, CA 91304
2	Sandia National Laboratories Combustion Sciences Dept. ATTN: R. Cattolica D. Stephenson Livermore, CA 94550
1	Science Applications, Inc. ATTN: R.B. Edelman 23146 Cumorah Crest Woodland Hills, CA 91364
1	Science Applications, Inc. ATTN: H.S. Pergament 1100 State Road, Bldg. N Princeton, NJ 08540
1	Space Sciences, INc. ATTN: M. Farber Monrovia, CA 91016
4	SRI International ATTN: S. Barker D. Crosley D. Golden Tech Lib 333 Ravenswood Avenue Menlo Park, CA 94025
1	Stevens Institute of Tech. Davidson Laboratory ATTN: R. McAlevy, III Hoboken, NJ 07030
1	Teledyne McCormack-Selph ATTN: C. Leveritt 3601 Union Road Hollister, CA 95023
1	Thiokol Corporation Elkton Division ATTN: W.N. Brundige P.O. Box 241 Elkton, MD 21921
3	Thiokol Corporation Huntsville Division ATTN: D.A. Flanagan Huntsville, AL 35807
3	Thiokol Corporation Wasatch Division ATTN: J.A. Peterson P.O. Box 524 Brigham City, UT 84302
1	United Technologies ATTN: A.C. Eckbreth East Hartford, CT 06108
2	United Technologies Chemical Systems Division ATTN: R. S. Brown R. O. McLaren P. O. Box 358 Sunnyvale, CA 94088
1	Universal Propulsion Company ATTN: H.J. McSpadden Black Canyon Stage 1 Box 1140 Phoenix, AZ 85029

DISTRIBUTION LIST

No. Of Copies	Organization
1	Brigham Young University Dept. of Chemical Engineering ATTN: M.W. Beckstead Provo, UT 84601.
1	Jet Propulsion Laboratory ATTN: MS 125/159 4800 Oak Grove Drive Pasadena, CA 91103
1	California Institute of Technology ATTN: F.E.C. Culick/ MC 301-46 204 Karman Lab. Pasadena, CA 91125
1	University of California, Berkeley Mechanical Engineering Dept. ATTN: J. Daily Berkeley, CA 94720
1	Los Alamos National Lab. ATTN: T.D. Butler P.O. Box 1663, Mail Stop B216 Los Alamos, NM 87545
2	University of California, Santa Barbara Quantum Institute ATTN: K. Schofield M. Steinberg Santa Barbara, CA 93106
1	University of Southern California Dept. of Chemistry ATTN: S. Benson Los Angeles, CA 90007
1	Case Western Reserve Univ. Div. of Aerospace Sciences ATTN: J. Tien Cleveland, OH 44135
1	Cornell University Department of Chemistry ATTN: E. Grant Baker Laboratory Ithaca, NY 14853
1	Univ. of Dayton Rsch Inst. ATTN: D. Campbell AFRPL/PAP Stop 24 Edwards AFB, CA 93523
1	University of Florida Dept. of Chemistry ATTN: J. Winefordner Gainesville, FL 32611
3	Georgia Institute of Technology School of Aerospace Engineering ATTN: E. Price Atlanta, GA 30332
2	Georgia Institute of Technology School of Aerospace Engineering ATTN: W.C. Strahle B.T. Zinn Atlanta, GA 30332
1	Hughes Aircraft Company ATTN: T.E. Ward 8433 Fallbrook Avenue Canoga Park, CA 91303
1	University of Illinois Dept. of Mechanical Eng. ATTN: H. Krier 144 MEB, 1206 W. Green St. Urbana, IL 61801
1	Johns Hopkins University/APL Chemical Propulsion Information Agency ATTN: T.W. Christian Johns Hopkins Road Laurel, MD 20707

DISTRIBUTION LIST

No. Of Copies	Organization
1	University of Minnesota Dept. of Mechanical Engineering ATTN: E. Fletcher Minneapolis, MN 55455
4	Pennsylvania State University Applied Research Laboratory ATTN: G.M. Faeth K.K. Kuo H. Palmer M. Micci University Park, PA 16802
1	Polytechnic Institute of NY ATTN: S. Lederman Route 110 Farmingdale, NY 11735
3	Princeton University Forrestal Campus Library ATTN: K. Brezinsky I. Glassman F. Williams P.O. Box 710 Princeton, NJ 08540
1	Princeton University MAE Dept., Eng. Quad. ATTN: F.A. Williams, D325 P.O. Box 710 Princeton, NJ 08540
2	Purdue University School of Aeronautics and Astronautics ATTN: R. Glick J.R. Osborn Grissom Hall West Lafayette, IN 47907
3	Purdue University School of Mechanical Engineering ATTN: N.M. Laurendeau S.N.B. Murthy D. Sweeney TSPC Chaffee Hall West Lafayette, IN 47906
1	Rensselaer Polytechnic Inst. Dept. of Chemical Engineering ATTN: A. Fontijn Troy, NY 12181
2	Southwest Research Institute ATTN: Robert E. White A.B. Wenzel 8500 Culebra Rd. San Antonio, TX 78228
1	Stanford University Dept. of Mechanical Engineering ATTN: R. Hanson Stanford, CA 94305
2	University of Texas Dept. of Chemistry ATTN: W. Gardiner H. Schaefer Austin, TX 78712
1	University of Utah Dept. of Chemical Engineering ATTN: G. Flandro Salt Lake City, UT 84112
1	Virginia Polytechnical Institute and State University ATTN: J.A. Schetz Blacksburg, VA 24061
1	North White Plains Senior High School ATTN: R.A. Nelson 96 Washington Avenue North White Plains, NY 10603

Aberdeen Proving Ground

Dir, USAMSAA
ATTN: DRXSY-D
DRXSY-MP, H. Cohen
Cdr, USATECOM
ATTN: DRSTE-TO-F
Dir, USACSL, Bldg. E3516, EA
ATTN: DRDAR-CLB-PA
DRDAR-CLN
DRDAR-CLJ-L

USER EVALUATION OF REPORT

Please take a few minutes to answer the questions below; tear out this sheet, fold as indicated, staple or tape closed, and place in the mail. Your comments will provide us with information for improving future reports.

1. BRL Report Number ______________________

2. Does this report satisfy a need? (Comment on purpose, related project, or other area of interest for which report will be used.)

____

____

____

3. How, specifically, is the report being used? (Information source, design data or procedure, management procedure, source of ideas, etc.) ______________________

____

____

4. Has the information in this report led to any quantitative savings as far as man-hours/contract dollars saved, operating costs avoided, efficiencies achieved, etc.? If so, please elaborate.

____

____

5. General Comments (Indicate what you think should be changed to make this report and future reports of this type more responsive to your needs, more usable, improve readability, etc.) ______________________

____

____

____

6. If you would like to be contacted by the personnel who prepared this report to raise specific questions or discuss the topic, please fill in the following information.

Name: ______________________

Telephone Number: ______________________

Organization Address: ______________________

____

____